FAST, VERSATILE POCKELS CELL DRIVER*

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Summary

Vacuum planar triodes, normally used in S-Band radar applications, can also serve as excellent switch tubes in fast, low jitter pulse generators. Laser systems have need of such generators for driving Pockels cells. Development work in this area has resulted in three successive driver designs. The present two-chassis unit will serve as a standard driver in the Nova and Novette laser systems. This assembly is capable of driving nine kilovolts into 75 ohms with three nanoseconds risetime and less than 100 picoseconds short term jitter. Rise and fall times of approximately two nanoseconds are available at half output voltage swing.

Introduction

Optical switches, based on a variety of physical phenomena, are widely used in large synchronized laser systems such as Argus, Shiva and Nova. The roles of these switches are several, including retropulse suppression, amplified spontaneous emmission (ASE) suppression, and, in conjunction with the optical oscillators at the head of the laser chain, switching out of a single pulse from a pulse train, or shaping a pulse out of a longer pulse.

Pockels cells, combined with polarizer plates, form fast optical switches particularly useful at the start of the laser chain, both for ASE suppression and for pulse switching and shaping. Drive requirements for these Pockels cells depend on the type of cell and the application. It is generally desired that the cells be driven with a half-wave voltage, which is the voltage required to rotate the polarization of the optical signal by 90 degrees. For small aperture cells (10 mm) two KD*P crystals in series are used for each device and the half-wave voltage is approximately 4.5 kilovolts. For larger apertures of 25 and 50 mm single KD*P crystals are employed, and the half-wave voltage is approximately nine kilovolts. The KD*P crystals represent capacitive loads, but the cells can be made to appear purely resistive by using a termination network, or by placing the crystal in an appropriate transmission line system. Hence, the driver must provide a high voltage pulse into the characteristic cable impedance. Gate times range from a few to approximately 50 nanoseconds. During this gate interval, the Pockels cell driver must maintain the pulse voltage to within 10 percent in order to achieve an optical transmission variation of less than three percent.

Two additional needs which narrow the field of possible driver candidates are low jitter and long lifetime at a repetition rate of 10 pulses per second (pps). Acceptable jitter is less than $\pm$ 100 picoseconds short term and $\pm$ 1 nanosecond long term (over a period of days). When operated in large systems, it is highly desirable that preventative maintenance be minimized and that reliability be such that corrective maintenance is a rare event. A list of potential devices considered for the output switch for the required driver is given in Table 1.

Vacuum triodes possess an interesting set of parameters which has led to the pursuit of a viable Pockels cell driver using these high-bandwidth planar devices, designed for S-Band radar modulators. Earlier tests[1] indicated that, in the time regime required, cathode currents of up to 20 amperes/cm^2 could be extracted at the 10 pps rate without unacceptable tube degradation. This contrasts with the five or so amperes/cm^2 specified by manufacturers, partially offsetting the comparatively low drive capability of vacuum tubes in comparison with spark gaps and thyratrons.

These tubes work well in the switched mode, with the grid driven several hundred volts positive. Corresponding grid current is several amperes, but the extremely low duty cycle avoids grid dissipation problems entirely.

An assessment of all fast Pockels cell drive requirements (Table 2) has led to the development of a standard driver capable of, with minor modifications, fulfilling all present laser system demands. Although slower than spark gap drivers, the planar triode's speed is adequate for Nova.

Circuit Description

The standard driver is contained in two, seven inch high rack-mounted chassis. A simplified schematic of the units is shown in Fig. 1. A straightforward, three transistor high avalanche stack dumps a charge line to provide grid drive for V1, the first tube. This stack is triggered fiber optically via a photodiode. No pulse charging is used in the entire driver; the single fiber optic trigger pulse is all that is required to produce the output pulse to the Pockels cell. The pulse width may be varied within the range of three to greater than 50 nanoseconds by changing the length of the charge line. This line is made up of two parallel lengths of RG-174 and is hence very compact.

All tubes operate in the grounded cathode mode. Because of the Miller effect (grid-plate capacitance multiplication), this mode is inherently slower than the grounded grid configuration, when triodes are used. The grounded cathode stage simplifies coupling and its use generally results in fewer overall tubes, while maintaining adequate speed for existing applications.

V1 serves to minimize the size of the transistor avalanche stack while providing hard grid drive to V2. Its output is stepped down by a transmission line transformer to match into V2. A second set of transmission line transformers couples V2's output to twin, 75 ohm outputs located on the rear panel of the first chassis. Nominal output from each is 1500

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volts peak, with well over 2000 volts typically available by increasing V2's anode voltage.

The second (driver) chassis contains six identical output stages. The circuitry is quite simple with a third set of transmission line transformers employed to match the twin 75 ohm coupling channels between chassis to six, 25 ohm grid drivers. The outputs are simply capacitively coupled and can be ganged together as desired to increase drive capability. Referring back to Table 2, the slow one cm cells (used for oscillator switchout) are typically found in groups of three to increase extinction ratio. Two tubes can adequately drive each cell via 100 ohm coaxial cable, so one standard unit is used to drive one three element switchout. For long (three nsec) optical pulse applications, the driver is used as a pulse carver. This presents the most demanding speed requirement on the driver. The pulse carver is similar to the switchout, but consists of only two dual cells. Three tubes are paralleled to drive each cell through a 50 ohm link, so a pulse carver requires only one driver chassis set. Finally, large Pockels cell applications require nine kilovolts of drive. For this, all six output tubes are paralleled. Originally, 50 ohm drive was used in this application, but the driver proved marginal with this loading. New designs reduce the necessary drive by going to a 75 ohm system. Since the inherent switching time of these large cells is comparatively slow, the higher impedance drive is of small consequence.

A photograph of the two chassis is shown in Figs. 2a and 2b. Both preamplifier and driver call upon stripline techniques to achieve the pulse performance attained. Although the circuitry is schematically simple, the illustrated product is the result of over two man years of experimental effort. Because of the low duty cycle (typically one part in 10^7), power supply requirements are minimal and readily available modular devices are used. The tube heaters are run off unregulated 6.3 volts a.c. with minimal problems, although further long-term stability measurements may dictate a constant voltage transformer in more critical applications.

Performance

Performance of the driver set is configuration dependent and still in the process of being improved. A representative five KV output pulse is depicted in Fig. 3, however. The leading edge transition time in this example is approximately 2.5 nanoseconds (10 to 90 percent), while the typically less critical trailing edge is somewhat slower. Since a Pockels cell exhibits a favorably nonlinear relationship between applied voltage and optical transmissibility

$$\left(T \propto \sin^2\left(\frac{\pi}{2}\,\frac{E}{E_0}\right)\right. \text{ where}$$

is the ratio of applied voltage to that voltage which produces maximum transmission) this electrical waveform results in optical switching time of 1.7 nanoseconds (10 to 90 percent).

Short-term jitter, referenced to the optical trigger, is less than 50 picoseconds, with the avalanche transistor stack the primary contributor to this figure. Long-term jitter (drift) is still under evaluation but is less than a nanosecond. The outstanding jitter performance of this approach was the prime motivation for its development.

Pulse amplitude stability has been the area of greatest difficulty with the units. Since the tubes are operated in a current regime not specified by the manufacturer, it was not surprising that approximately 10 percent of new tubes degrade markedly (to less than 50 percent of initial output) after a few days use. Most of the remainder hold up quite well, degrading less than 20 percent over an extended period of continuous operation at 10 pps.

Future Development

Several minor, evolutionary changes are still being incorporated into the design. Power supply types are being changed in some cases to reduce cost, provide independent adjustment of grid bias, or to provide additional current capability. A development effort also continues on the avalanche transistor module, with a double stack under consideration to sharpen the trailing edge of the pulse.

In the longer term, even faster switching times are desired for pulse carving applications. Further improvement will require use of the grounded grid configuration throughout and even more care in transformer and coupling design and experimental development. Based on work by Pico Second Enterprises, Oakland, CA, with similar units, optical switching times approaching 500 picoseconds appear possible.

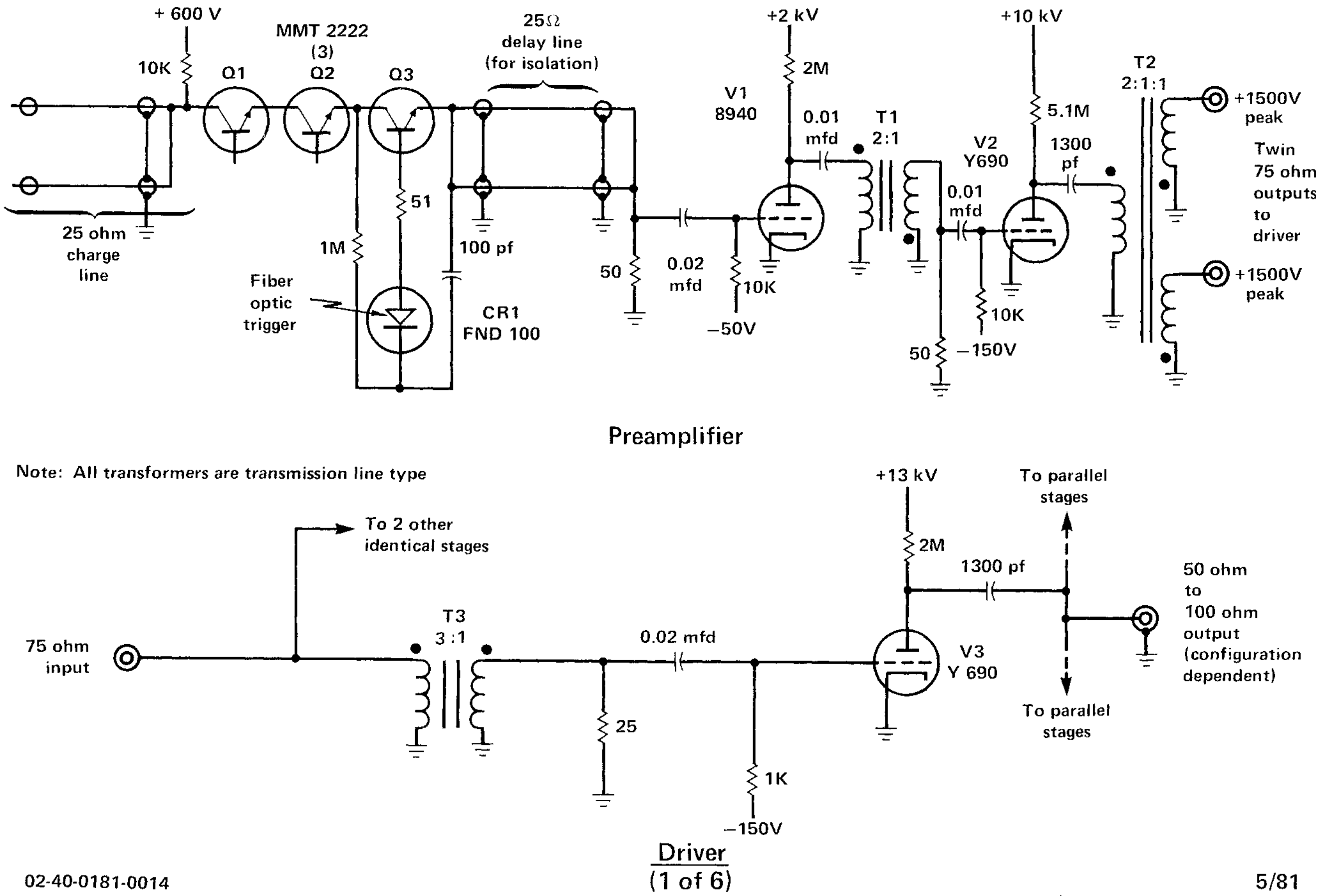
It is also desired to reduce the complexity of the driver, hence improving its reliability. The chief complexity contributor is the limited current drive capability of the tubes, requiring output paralleling. The Eimac division of Varian, Inc., Salt Lake City, UT, is currently funded to develop significantly larger area cathode tubes with the same high bandwidth as the existing two cm^2 units. To do this, the planar geometry is being abandoned in favor of a more complex. but more stable, domed configuration. Experimental two cm^2 tubes have been built, with a cutaway example shown in Fig. 4. Manufacturing techniques have been developed and experimental three cm^2 cathode area tubes are now being fabricated. Ultimately, four cm^2 or larger tubes meeting bandwidth requirements may be practical

Conclusions

The planar triode driver presented in the latest version of a continually evolving unit. Three examples have accumulated considerable operational time on the Shiva laser system and operational characteristics and reliability performance are becoming increasingly well understood. Although limited in drive capability in comparison with most competitive techniques, requiring paralleling of several triodes to achieve the desired output, the utility of the driver surpasses all previously used approaches. Continuing design clean-up and the implementation of routine new unit burn-in promise to further minimize required attention when installed on operating systems. Further development using grounded grid circuitry could provide even faster switching times, and large area cathode tubes hold promise of reduced complexity and perhaps cost.

References

1. M. Howland, S. Davis, and W. Gagnon, "Very Fast, High Peak Power Planar Triode Amplifiers for Driving Optical Gates," 2nd IEEE International Pulsed Power Conference, Lubbock, Texas, June 12-14, 1979.



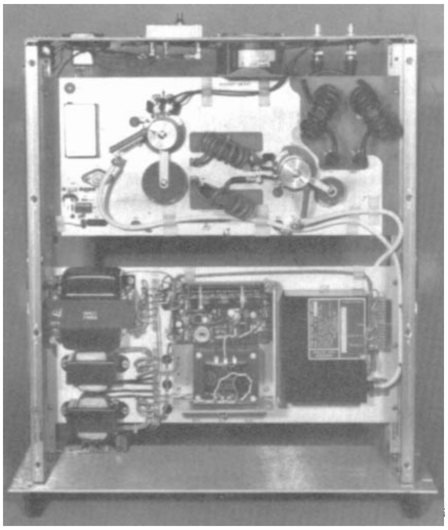
Simplified Schematic Diagram
Figure 1

TABLE 1
Switching Device Comparison

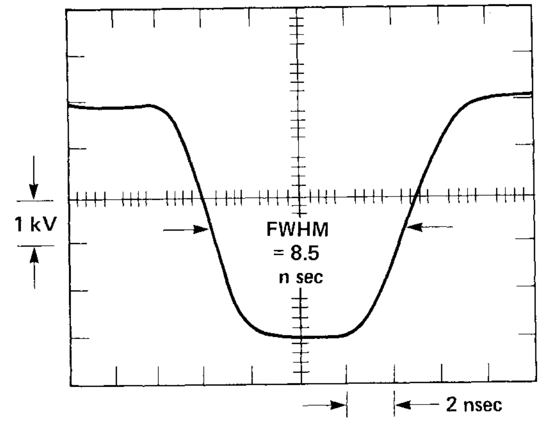
Device	Risetime	Jitter	Drive Capability	Maintenance/ Lifetime/ Reliability	Complexity/ Cost
Gas switch* (spark gap)	2	5	1	3	1
Krytron	5	6	3	5	2
Thyratron	6	3	2	1	3
Solid state avalanche stack	4	4	6	4	6
Vacuum triode	3	2	5	2	4
Auston switch	1	1	4	**	5

* Laser triggering offers improved jitter at cost of greatly increased complexity
** Too new to assess

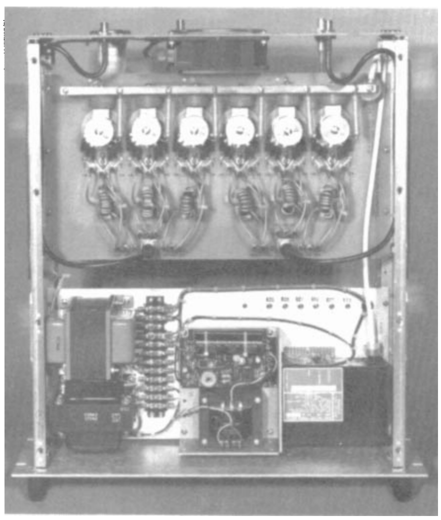
1 = Most favorable
6 = Least favorable



Preamplifier Chassis
Figure 2a



Typical Output Waveform
Figure 3



Driver Chassis
Figure 2b

Experimental Domed Triode
Figure 4

TABLE 2
Pockels Cell Driver Applications

Device	Drive Voltage (kV)	Drive Impedance (ohms)	Required Risetime (nsec)	Inherent Cell Risetime (nsec)	Cell Capacitance (picofarads)
Slow 1 cm cells	4.5	100	4	<0.7	14
Fast 1 cm cells (pulse carver)	4.5	50	2.5*	<0.7	14
2.5 & 5 cm cells	9	75	5	2/3	20/40

* <1 for future applications